New Probable Dwarf Galaxies in Northern Groups of the Local Supercluster

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Abstract We have searched for nearby dwarf galaxies in 27 northern groups with characteristic distances 8–15 Mpc based on the Second Palomar Sky Survey prints. In a total area of about 2000 square degrees, we have found 90 low-surface-brightness objects, more than 60% of which are absent from known catalogs and lists. We have classified most of these objects (80%) as irregular dwarf systems. The first 21-cm line observations of the new objects with the 100-m Effelsberg radio telescope showed that the typical linear diameters (1–2 kpc), internal motions (30 km s^{-1}), and hydrogen masses ($\sim 2 \times 10^7 M_\odot$) galaxies correspond to those expected for the dwarf population of nearby groups.

Keywords: dwarf galaxies, groups of galaxies.

1 INTRODUCTION

A clear definition of galaxy membership in a group is required to analyze the kinematics and dynamics of the groups of galaxies. However, the groups of galaxies are defined in different ways, depending on the adopted selection algorithm and the galaxy sample to which this algorithm is applied.

Supplementing the groups by adding new dwarf galaxies makes it possible to study in more detail the galaxy luminosity function, the morphological segregation in groups, and the dependence of the chemical composition of dwarf galaxies and the star formation rate in them on their immediate environment. The problem of discrepancy between predictions of the Lambda-CDM-model (Klypin et al. 1999) and observational data has not yet been solved: the currently known number of dwarf galaxies in the Local Group is approximately an order of magnitude smaller than the predicted number. Thus, finding new dwarf galaxies in nearby groups remains a very topical problem.

The chance of detecting and identifying dwarf galaxies decreases sharply with distance. The groups selected from (either "optical," CGC (Zwicky et al. (1961–1968), or "infrared," 2MASS (Cutrie and Skrutskie 1998)) flux-limited catalogs contain virtually no dwarf galaxies. At the same time, purposeful thorough searches for putative dwarf members of the Local Volume in the POSS-II and ESO/SERC sky surveys out to distances of 5–6 Mpc proved to be successful (for more detail, see the Catalog of Nearby Galaxies (CNG) by Karachentsev et al. (2004)). These searches doubled the number of confirmed dwarf galaxies in the nearest groups, which made it possible to study in detail the kinematics and dynamics of the Local Volume groups (Karachentsev 2005). Based on the similarity between the functions of the linear

diameters of galaxies in the Local Group and the nearest groups, we undertook independent searches for the dwarf population in the more distant (10.4 Mpc) Leo-I group (Karachentsev and Karachentseva 2004). This required decreasing the limiting angular diameter of the sought-for dwarf members of Leo-I from 0.6–0.5 arcmin to 0.4–0.3 arcmin. We found 36 candidates for dwarf objects in the Leo-I group. HI 21-cm line observations with the 300-m Arecibo radio telescope confirmed the membership of most of them in the group (Stierwalt et al. 2005). This encouraging result allowed us to undertake searches for new probable dwarf members in other nearby groups of the Local Supercluster.

As we see from Table 1, the number of detected candidates for new group members depends weakly on the distance to the group (in the interval under consideration) and on its population. Note, however, that we found the largest number of new objects in groups where the brightest member is an early-type galaxy (NGC 1023, NGC 3607).

2 RESULTS OF OUR SEARCHES

As the initial sample, we took the 2004 version of the Catalog of Groups of Galaxies of the Local Supercluster with radial velocities $V_{LG} < 3100$ km s^{-1} (Makarov and Karachentsev 2000). We selected the groups that satisfied the following three conditions from this catalog: (1) the number of galaxies in the group $N \geq 4$; (2) the mean radial velocity reduced to the Local Group centroid $< V_{LG} >= 550 - 1100$ km s^{-1}; and (3) a positive declination of the group center. There were 43 such groups. Subsequently, we excluded the groups located in the Virgo cluster from our searches, because of the complex dynamical pattern and the difficulty of clearly separating its subsystems. Table 1 gives a list of groups studied. Its columns present the following characteristics:

–name of the dominating galaxy in the group;

–mean radial velocity in km s^{-1};

–number of group members with known radial velocities; the number of elliptical galaxies among them is given in parentheses;

–morphological type of the dominating galaxy on the RC3 scale (de Vaucouleurs et al. 1991);

–numbers of the POSS-II fields in which the searches were constructed;

–number of detected presumed dwarf members of the group without radial velocities; the number of new objects is given in parentheses.

We carried out our searches on the blue (B) and red (R) POSS-II prints to a limiting angular size of 0.4–0.3 arcmin. We examined wide neighborhoods of the groups in order that the radius of the search region be twice the harmonic mean radius of the group. The results of our searches are summarized in Table 2, where the following data are presented:

–object name, where "d" stands for "dwarf," followed by two four-digit sequences indicating the hours and minutes in right ascension and the degrees and minutes in declination;

–right ascension and declination for epoch J2000.0;

– type of dwarf galaxy:Ir–irregular, Sph– spheroidal, dE–elliptical;

–major and minor axes measured on the blue print;

–name of the group to which the object presumably belongs;

–notes and identification with known lists made using the NED database.

All of the objects found have a low surface brightness. In the notes, VLSB and ELSB stand for very low ($\sim 25^m$ arcsec^{-2}) and extremely low ($\sim 26^m$ arcsec^{-2}) surface brightness,

Table 1: Groups in which dwarf galaxies were searched for

Group (1)	$< V_{LG} >$ (2)	$N(N_E)$ (3)	Type (4)	POSS-II field numbers (5)	Number of objects (6)
NGC 1023	824	17 (1)	−3	299; 355; 356	12 (12)
NGC 2681	752	6 (2)	0	211	0 (0)
NGC 2841	653	8 (2)	3	212	1 (0)
NGC 3180	565	4 (0)	6	316; 317	1 (1)
NGC 3486	621	4 (0)	5	438	0 (0)
NGC 3507	957	18 (2)	3	569; 570; 640	1 (0)
NGC 3607	854	11 (7)	−2	570	21 (17)
NGC 3627	705	6 (0)	4	641; 642; 713; 714	4 (3)
NGC 3686	1038	7 (0)	4	641; 642	1 (0)
NGC 3726	926	20 (3)	5	216; 217; 266	0 (0)
NGC 3938	805	8 (2)	5	266; 267	0 (0)
NGC 3953	1092	18 (4)	4	170; 171; 216; 217	4 (2)
NGC 3972	871	4 (0)	4	171	0 (0)
NGC 4062	728	4 (0)	5	440; 379	1 (1)
NGC 4088	826	8 (0)	5	216; 217; 266; 277	0 (0)
NGC 4151	1051	10 (0)	2	321; 322; 379; 380	0 (0)
NGC 4183	972	4 (2)	6	217; 218; 267	2 (1)
NGC 4258	561	9 (0)	4	216; 217; 267	5 (2)
NGC 4274	957	8 (1)	2	441	12 (3)
NGC 4278	609	10 (3)	−5	441; 442	6 (3)
NGC 4346	793	5 (1)	−2	218; 267; 268	1 (0)
NGC 4490	602	9 (0)	7	268; 322	3 (2)
NGC 4559	740	13 (4)	6	380; 381; 442	5 (2)
NGC 5033	996	15 (1)	5	323; 324; 382	3 (2)
NGC 5194	611	7 (1)	5	220; 269; 270; 323	2 (0)
NGC 5248	1087	6 (0)	4	720	1 (1)
NGC 5906	913	13 (4)	5	176; 177	2 (2)

respectively.

Our independent searches revealed objects that either were found previously (Karachentseva and Karachentsev 1998 (KK); Karachetnsev et al. 2001 (KKH) or were included in the lists of other authors (Binggeli et al. 1990 (BST); Shombert et al. 1997 (D); Trentham and Tully 2002 (ComaI); Cabanela 1999 (MAPS); Trentham et al. 2001 (TTV)). Table 2 includes those of them that have no measured radial velocities. The object d1223+2935, whose radial velocity was determined with a large error, was left in Table 2 for further observations. In addition, we included the object d1243+4127, a possible member of the NGC 4736 group missed when the lists of presumed dwarf members of the Local Volume were published, in the list. Several objects, to be described in more detail below, stand out among those found.

(1) d0226+3325. This is an object of extremely low surface brightness located 13 arcmin SW of the galaxy NGC 925. This galaxy lies on the periphery of the NGC 1023 group and was included in the catalog of isolated galaxies (Karachentseva 1973) as CIG 105. HI mapping of

the spiral NGC 925 and its neighborhood revealed a hydrogen satellite connected with NGC 925 by a "bar" (Briggs 1980; Gottesman 1980). Pisano et al. (1998) pointed out that there is a hydrogen cloud with a radial velocity of $V_h = 524$ km s^{-1} and a line FWHM $W_{50} \sim 40$ km s^{-1} at 10 arcmin SW of NGC 925. Note that the mean measured velocity of NGC 925 is $V_h = 553$ km s^{-1}. The hydrogen mass of the cloud was estimated to be $10^7 M_\odot$. The cloud is invisible on a deep R-band image obtained by these authors with the WINM telescope. The object we found is probably an extremely low surface brightness object and is the optical counterpart of the "hydrogen cloud."

(2) A close "triplet" in the NGC 1023 group. Our observations (see Table 3) show that the dwarf galaxies d0245+3955, d0245+3957, and d0246+3952 are members of a single group.

(3) d1228+4358. This object appears as a partially destroyed "tail" pointing away from the galaxy NGC 4449 southward. It is similar in size, low surface brightness, and diffuse structure to the dwarf system KK 208 with an old stellar population near NGC 5236 (Karachentsev et al. 2002). This may be an example of the formation of the so-called tidal dwarfs or, conversely, the capture of a dwarf system by a bright galaxy just like the Sagittarius dSph phenomenon around the Milky Way. The figure presents the images of the six new dwarf galaxies mentioned above from the Digital Sky Survey. Each image corresponds to the blue POSS-II prints. As we see from Table 2, more than 60% of the objects are absent from known catalogs and lists. The median of the distribution of new objects in angular diameter is 0.4 arcmin, which is half that for the known objects. At a characteristic distance to the groups of 12 Mpc, the median linear diameter of the new galaxies is about 1.5 kpc, which is typical of the dwarf population of the Local Group and other nearby groups. According to our estimates, about 80% of the objects in Table 2 are irregular dwarf galaxies. In such systems, a significant fraction of the mass is usually accounted for by neutral hydrogen (HI), which makes their 21-cm line observations promising.

3 21-cm LINE OBSERVATIONS

The objects from Table 2 were observed in 2005–2006 with the 100-m Effelsberg radio telescope. At a beam width (FWHM) of the radio telescope equal to 9.3 arcmin, the angular sizes of the objects we found occupy only a small fraction of its aperture. Therefore, a considerable accumulation time is required to detect the HI flux from them. Small angular separations between group galaxies are another problem, which occasionally causes confusion of the signals from several objects that fell within the aperture of the radio telescope.

Table 3 presents the results of our observations for several detected galaxies where no confusion arose because of close neighbors. Its columns present the following: 1, equatorial coordinates of the galaxy; 2, HI flux in Jy km s^{-1}; 3, maximum emission and (or) its rms error in mJy; 4, heliocentric radial velocity and its error in km s^{-1}; 5, line full width at half maximum; 6, total apparent magnitude of the galaxy that we estimated on the blue POSS-II print compared to other galaxies of similar morphology; 7, absolute magnitude of the galaxy corrected for the Galactic extinction as derived by Schlegel et al. (1998) for an assumed distance to the galaxy of $D = V_{LG}/H$, where $H = 72$ km s^{-1}Mpc^{-1}; 8, HI mass-to-light ratio in solar units, where the hydrogen mass was determined from the HI flux F as $\log M_{HI} = \log F + 2 \log D + 5.37$. Judging by their low radial velocities, weak HI fluxes, and small line widths, these objects are actually dwarf galaxies with a typical hydrogen masses of $\sim 2 \times 10^7 M_\odot$. The HI survey of the galaxies listed in Table 2 is not yet complete. We are

Table 2: List of new galaxies found in 27 nearby northern groups

Name	RA (2000.0) DEC	Type	$(a \times b)$'	Group	Notes
(1)	(2)	(3)	(4)	(5)	(6)
d0224+4102	022420.7+410212	Ir	0.50x0.30	N1023	
d0226+3325	022652.8+332537	Sph	1.30x1.20	N1023	ELSB at 13' SW of925
d0237+4136	023718.8+413607	Ir	0.40x0.35	N1023	LSB
d0238+4052	023851.2+405247	Ir	0.70x0.40	N1023	VLSB
d0241+3653	024131.5+365327	Ir	0.70x0.40	N1023	Wedge-shaped
d0243+3759	024302.0+375926	Sph	0.60x0.50	N1023	
d0245+3955	024530.8+395547	Ir	0.35x0.30	N1023	
d0245+3957	024550.7+395711	Ir	0.90x0.75	N1023	
d0246+3952	024600.6+395238	Ir	0.70x0.50	N1023	
d0246+3910	024612.4+391055	Ir	0.75x0.50	N1023	Distant spiral ?
d0246+3249	024621.8+324945	Ir	0.65x0.35	N1023	VLSB
d0246+3832	024649.0+383251	Ir	0.40x0.25	N1023	
d0921+5016	092157.1+501612	Sph	1.10x0.90	N2841	KKH 49
d1018+4109	101822.6+410958	Ir	0.60x0.40	N3180	LSB, blueish
d1106+1250	110610.5+125042	Ir	0.50x0.25	N3507	D 640-9
d1110+1932	111037.6+193217	Ir	0.35x0.30	N3607	
d1112+1845	111257.5+184540	dE	0.70x0.40	N3607	F 570-4, distant?
d1114+1802	111422.9+180235	Ir	0.40x0.30	N3607	Sph?
d1115+1758	111507.1+175815	Ir	0.25x0.25	N3607	dE?
d1115+1755	111513.0+175545	dE	0.30x0.25	N3607	
d1115+1756	111524.5+175635	Ir	0.50x0.40	N3607	dE? 19.5^m(MAPS)
d1115+1801	111536.4+180108	Ir	0.45x0.40	N3607	Sph? ELSB
d1115+1804	111548.1+180438	Ir	0.25x0.25	N3607	VLSB
d1115+1756	111558.0+175620	Ir	0.40x0.30	N3607	
d1116+1757	111611.7+175700	Ir	0.35x0.30	N3607	D570-5
d1116+1713	111621.0+171347	Sph	0.25x0.25	N3607	ELSB
d1117+1818	111702.0+181807	Ir	0.45x0.35	N3607	
d1117+1719	111708.1+171909	Ir	0.30x0.25	N3607	
d1117+1759	111722.7+175945	Ir	0.30x0.25	N3607	VLSB
d1117+1815	111748.2+181500	Ir	0.60x0.50	N3607	distant spiral?
d1117+1737	111756.9+173726	dE	0.70x0.30	N3607	Sph?, 18.8^m(MAPS)
d1119+1157	111914.6+115709	Ir	1.00x0.35	N3627	17.9^m (MAPS)
d1119+1404	111921.5+140434	Ir	0.65x0.45	N3627	
d1119+1732	111921.9+173214	Ir	0.40x0.35	N3607	Sph?
d1120+1332	112016.1+133249	Ir	0.60x0.35	N3627	Satellite of N 3628
d1121+1830	112153.8+183008	Ir	0.35x0.30	N3607	
d1123+1916	112341.8+191615	Ir	0.55x0.45	N3607	
d1123+1816	112355.0+181657	Ir	0.40x0.30	N3607	
d1124+1125	112410.9+112514	dE	0.40x0.30	N3627	distant?
d1134+1709	113416.2+170946	Sm	0.70x0.40	N3686	KK 107

Table 2: continued

d1142+5210	114230.1+521036	Ir?	0.30x0.25	N3953	
d1148+5555	114843.8+555545	Ir	0.60x0.45	N3953	KK 110=TTV15, 16.6^m
d1150+5546	115006.3+554657	Ir	1.00x0.70	N3953	KKH 73, 16.5^m
d1154+3635	115423.9+363504	Ir	0.70x0.60	N4062	
d1156+5548	115601.2+554846	Ir	0.45x0.30	N3953	
d1205+4342	120525.0+434227	Ir	0.80x0.50	N4183	KK 121
d1212+4237	121218.0+423732	Ir	0.50x0.45	N4183	
d1214+2749	121442.3+274955	Ir	0.35x0.30	N4274	
d1214+2915	121443.4+291511	Ir?	0.30x0.30	N4274	ComaI-19,Sph?, VLSB,
d1215+2813	121541.2+281315	Ir?	0.40x0.30	N4274	distant spiral?
d1215+2917	121547.8+291728	Ir	0.30x0.30	N4274	ComaI-16, 19.5^m
d1216+2928	121639.2+292846	Ir	0.30x0.25	N4274	ComaI-12, VLSB, 19.2R
d1217+4703	121710.1+470349	Ir	0.35x0.25	N4258	BTS 109, Sph?, VLSB, 18.5^m
d1217+2914	121747.2+291436	Ir	0.40x0.40	N4274	ComaI-9, 18.1^m
d1217+2828	121748.6+282827	dE	0.70x0.45	N4274	KDG95= KK 130, 19.6^m
d1218+2838	121829.4+283845	Ir	0.80x0.70	N4274	KDG98= KK131=BTS115, 16.5^m
d1218+3003	121831.8+300336	Ir	0.70x0.35	N4274	18.2^m(MAPS)
d1218+2938	121843.6+293804	Ir	0.40x0.35	N4274	ComaI-17, ELSB, 19.9R
d1218+2833	121857.2+283312	dE	1.10x0.60	N4274	BTS116, 15.5^m
d1219+4743	121906.5+474351	Ir	0.60x0.50	N4258	KK 132, VLSB
d1219+4727	121933.8+472706	dE	0.30x0.30	N4258	BTS118=KK134, 17.0^m
d1219+4705	121936.8+470533	Sph	0.25x0.25	N4258	LSB
d1219+2939	121943.8+293933	dE	0.60x0.40	N4274	BTS119, 17.5^m
d1210+4700	122040.6+470003	dE	0.30x0.30	N4258	BTS132=KK 136, 17.5^m, Ir?
d1220+4649	122055.0+464945	Sph	0.30x0.25	N4258	ELSB
d1221+2929	122108.8+292926	Ir	0.45x0.35	N4278	ComaI-13,VLSB, 19.6R
d1221+2905	122145.8+290502	Ir?	0.35x0.30	N4278	distant spiral?
d1223+2832	122309.5+283235	Ir?	0.30x0.30	N4278	VLSB
d1223+2935	122357.7+293547	dE	0.70x0.65	N4278	Vh=765±57, 18.4^m(MAPS)
d1224+4707	122412.0+470724	dE	0.40x0.35	N4346	BTS134, 17.0^m
d1228+4358	122844.9+435818	Ir	4: x 1:	N4490	VLSB
d1229+3056	122941.2+305641	Ir	0.40x0.30	N4278	Sph?
d1230+3002	123025.8+300224	Ir	0.55x0.40	N4278	VLSB, KDG 146
d1233+3806	123307.4+380658	Ir	0.50x0.40	N4490	BTS142, 17.5^m
d1238+3512	123854.6+351218	Ir	0.40x0.35	N4559	VLSB
d1242+4115	124212.3+411509	Sph	0.60x0.60	N4490	VLSB
d1243+3228	124325.2+322855	dE	1.10x0.60	N4559	BTS151, 16.0^m
d1243+2956	124344.2+295603	Ir	0.60x0.40	N4559	BTS152, 17.5^m
d1243+3232	124345.3+323201	Ir?	0.35x0.30	N4559	
d1243+4127	124355.7+412725	Ir	1.40x0.60	N4736	missed in KK lists
d1248+3158	124852.8+315815	Ir	0.70x0.50	N4559	KK 165=BTS156, 17.0^m
d1251+4704	125114.5+470406	Ir	0.70x0.50	—	BTS157, 17.5^m
d1310+3648	131058.7+364813	Ir	0.35x0.25	N5033	VLSB

Table 2: continued

d1310+3649	131059.1+364943	Ir	0.60x0.30	N5033	VLSB
d1311+3710	131106.6+371041	Ir	0.90x0.65	N5033	KK 188, near N5005
d1317+4423	131719.5+442348	Ir	0.80x0.50	N5194	KK 194, VLSB
d1332+4949	133236.2+494949	Ir	1.20x0.65	N5194	UGCA 361,dE?
d1337+0908	133733.2+090815	Ir	0.25x0.25	N5248	VLSB
d1504+5538	150451.2+553842	Ir	0.35x0.30	N5906	
d1508+5515	150832.5+551548	Ir	0.50x0.40	N5906	Knotty

Table 3: HI observations of several galaxies

RA (2000.0) DEC	F_{HI}	Smax	V_{HI}	W_{50}	B_T	M_B	M_{HI}/L_B
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
024530.8+395547	0.33	12±2	697±6	26	18.1	−12.7	1.5
024550.7+395711	0.66	19±2	551±9	36	16.8	−13.6	0.4
024600.6+395238	1.4	2	549±4	44	17.0	−13.4	1.0
115006.3+554657	0.5	8±2	594±6	20	16.5	−13.4	0.3
123307.4+380658	0.46	21±3	719±4	23	17.5	−12.6	0.7
124344.2+295603	0.99	44±4	1141±3	22	17.5	−13.8	1.5
124355.7+412725	1.2	51±4	402±2	16	16.2	−12.8	0.5

going to publish the complete results of our observations after the completion of the program.

4 CONCLUSIONS

Using the POSS-II prints, we examined the regions of 27 northern groups of galaxies with expected distances of about 12 Mpc (mean radial velocities in the range 550–1100 km s^{-1}) and with more than three members. The total number of members in these groups with measured radial velocities is 252. As a result of our searches, we added 90 more galaxies without radial velocities, which we consider to be probable members of these groups as low-surface brightness dwarf systems with typical angular sizes of 0.4 arcmin, to this list. Most of them are classified as dIr galaxies (80%); the remaining galaxies are classified as dE and dSph.

We observed some of the new objects in the 21-cm HI line with the 100-m Effelsberg radio telescope. These observations confirmed that the detected objects could be attributed to the dwarf population of the groups under consideration with a typical diameter of 1.5 kpc, an absolute magnitude of -13^m, inner motions of 30 km s^{-1}, a hydrogen mass of $\sim 2 \times 10^7 M_\odot$, and an HI mass-to-light ratio of $\sim 1 M_\odot/L_\odot$. The radial velocity measurements from the 21-cm line or optical spectra that we are planning will allow us to improve the luminosity function of the galaxies in nearby groups and to make the estimates of their virial masses more reliable.

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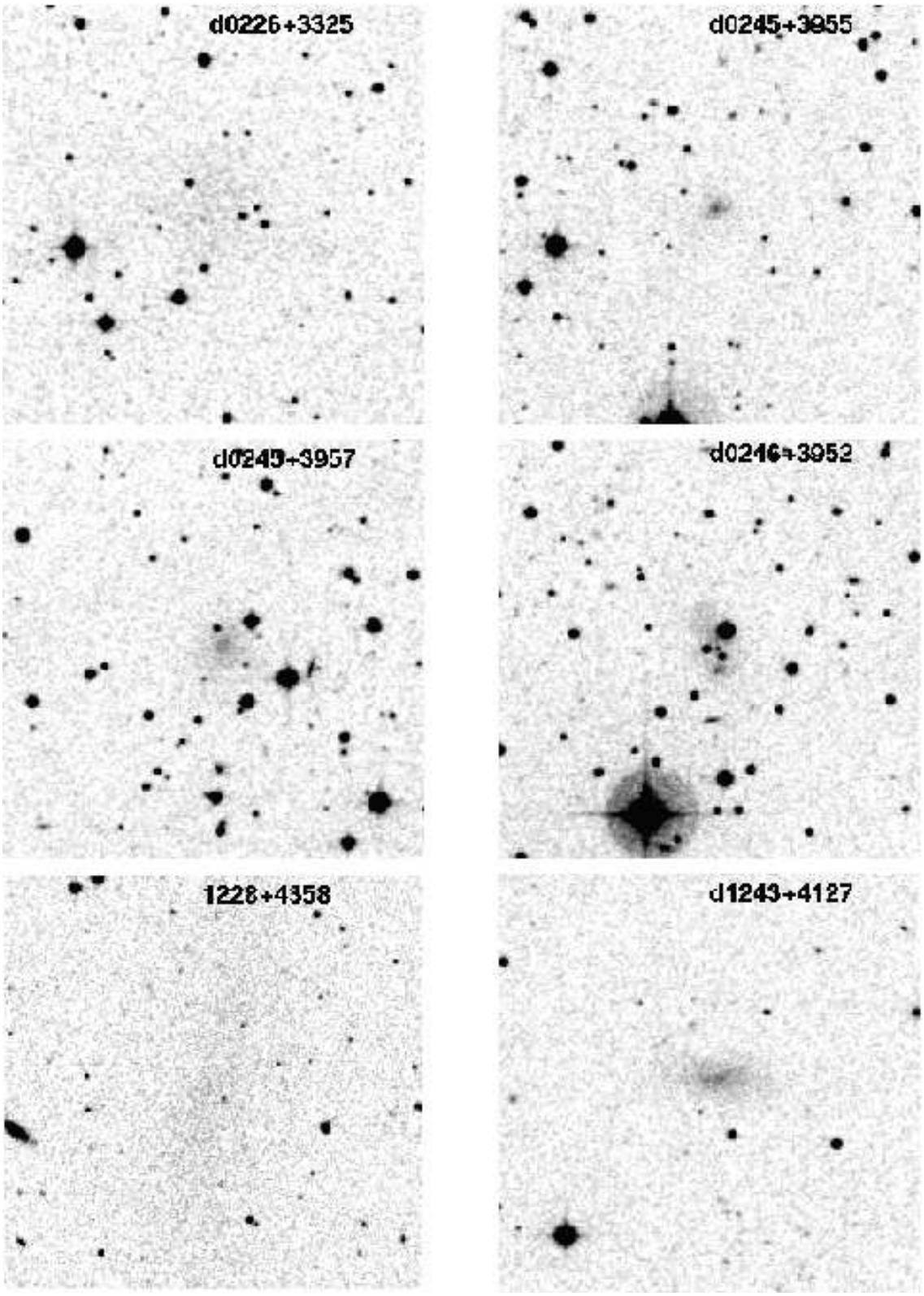

Figure 1: Reproductions of the images of six new low surface brightness dwarf galaxies from the blue POSS-II prints. Each field is 5 arcmin×5 arcmin in size; north is at the top and east is on the left.